

Amendments to the Specification

Please amend the Abstract as follows.

An apparatus for carrying out a process of converting hydrocarbon fuel to a hydrogen rich gas including a first heat exchanger for heating the hydrocarbon fuel to produce a heated hydrocarbon fuel, a first desulfurization reactor for reacting a the heated hydrocarbon fuel to produce a substantially desulfurized hydrocarbon fuel, a manifold for mixing the substantially desulfurized hydrocarbon fuel with an oxygen containing gas to produce a fuel mixture, a second heat exchanger for heating the fuel mixture to produce a heated fuel mixture, an autothermal reactor including a catalyst for reacting the heated fuel mixture to produce a first hydrogen containing gaseous mixture, a second desulfurization reactor for producing reacting the first hydrogen containing gaseous mixture to produce a second hydrogen containing gaseous mixture that is substantially desulfurized, a water gas shift reactor for reacting the second hydrogen containing gaseous mixture to produce a third hydrogen containing gaseous mixture with a substantially decreased carbon monoxide content, and a selective oxidation reactor for reacting the third hydrogen containing gaseous mixture to produce the hydrogen rich gas.

Please amend the paragraph beginning on page 6, line 15 as follows:

Process step C is a purifying step. One of the main impurities of the hydrocarbon stream is sulfur, which is converted by the autothermal reforming process of process step A to hydrogen sulfide. The processing core used in process step C preferably includes zinc oxide and/or other material capable of absorbing and converting hydrogen sulfide, and may include a support (e.g., monolith, extrudate, pellet etc.). Desulfurization is accomplished by converting the hydrogen sulfide to water in accordance with the following reaction formula.

III:



Please amend the paragraph beginning on page 8, line 7 as follows:

Process step E' [[F]] is a cooling step performed in one embodiment by a heat exchanger. The heat exchanger can be of any suitable construction including shell and tube, plate, spiral, etc. Alternatively a heat pipe or other form of heat sink may be utilized. The goal of the heat exchanger is to reduce the temperature of the gas stream to produce an effluent having a temperature preferably in the range of from about 90° C to about 150° C.

Please amend the paragraph beginning on page 8, line 13 as follows:

Oxygen is added to the process in step E' [[F]]. The oxygen is consumed by the reactions of process step G described below. The oxygen can be in the form of air, enriched air, or substantially pure oxygen. The heat exchanger may by design provide mixing of the air with the hydrogen rich gas. Alternatively, the embodiment of process step D may be used to perform the mixing.

Please amend the paragraph beginning on page 9, line 13 as follows:

The effluent exiting the fuel processor is a hydrogen rich gas P containing carbon dioxide and other constituents which may be present such as water, inert components (e.g., nitrogen, argon), residual hydrocarbon, etc. Product gas may be used as the feed for a fuel cell or for other applications where a hydrogen rich feed stream is desired. Optionally, product gas may be sent on to further processing, for example, to remove the carbon dioxide, water or other components.

Please amend the paragraph beginning on page 9, line 26 as follows:

The process equipment described herein may be fabricated from any material capable of withstanding the operating conditions and chemical environment of the reactions described herein and can include, for example, carbon steel, stainless steel, ~~Inconel INCONEL® (a trademark registered for use in association with nickel alloys and alloys of nickel, chromium and iron)~~, Incoloy, Hastelloy, and the like. The operating pressure for the process units are preferably from about 0 to about 100 psig, although higher pressures may be employed. Ultimately, the operating pressure of the fuel processor depends upon the delivery pressure required by the users of the product hydrogen, namely a fuel cell. For fuel cells operating in the 1 to 20 kW range an operating pressure of 0 to about 100 psig is generally sufficient.

Please amend the paragraph beginning on page 9, line 26 as follows:

Fuel processor 200 as shown in FIG. 2 similar to the process diagrammatically illustrated in FIG. 1 and described supra. Hydrocarbon fuel feed stream F is introduced to the fuel processor and hydrogen rich product gas P is drawn off. Fuel processor 200 includes several process units that each perform a separate operational function and is generally configured as shown in FIG. 2. In this illustrative embodiment, the hydrocarbon fuel feed [[F]] enters the first compartment 101 into spiral exchanger 201, which preheats the feed [[F]] against fuel cell tail gas T (enters fuel processor 200 at reactor 214). Because of the multiple exothermic reactions that take place within the fuel processor, one of skill in the art should appreciate that several other heat integration opportunities are also plausible in this service. This preheated feed then enters desulfurization reactor 202 through a concentric diffuser for near-perfect flow distribution and low pressure drop at the reactor inlet. Reactor 202 contains a desulfurizing catalyst and operates as described in process step C of FIG. 1. Note that this step does not accord with the order of process steps as presented in FIG. 1. This is a prime example of the liberty that one of skill in the art may exercise in optimizing the

process configuration in order to process various hydrocarbon fuel feeds and/or produce a more pure product. Desulfurized fuel from reactor 202 is then collected through a concentric diffuser and mixed with air [[A]], with the mixture being routed to exchanger 203. In this illustrative embodiment, exchanger 203 is a spiral exchanger that heats this mixed fuel/air stream against fuel cell tail gas T (enters fuel processor 200 at reactor 214).

Please amend the paragraph beginning on page 10, line 24 as follows:

The preheated fuel/air mixture then enters the second compartment 102, with the preheat temperature maintained or increased by electric coil heater 204 located between the two compartments. The preheated fuel-air mixture enters spiral exchanger 205, which preheats the stream to autothermal reforming reaction temperature against the autothermal reformer 206 effluent stream. Preheated water (enters fuel processor 200 at exchanger 212) is mixed with the preheated fuel-air stream prior to entering exchanger 205. The preheated fuel-air-water mixture leaves exchanger 205 through a concentric diffuser and is then fed to autothermal reformer (ATR) 206, which corresponds to process step A of FIG. 1. The diffuser allows even flow distribution at the ATR 206 inlet. The hot hydrogen product from ATR 206 is collected through a concentric diffuser and routed back to exchanger 205 for heat recovery. In this embodiment, exchanger 205 [[206]] is mounted directly above ATR 206 in order to minimize flow path, thereby reducing energy losses and improving overall energy efficiency. Flow conditioning vanes can be inserted at elbows in order to achieve low pressure drop and uniform flow through ATR 206.

Please amend the paragraph beginning on page 11, line 16 as follows:

Air [[A]] is then introduced to the cooled shift reaction product, which is then routed to a concentric diffuser feeding preferred CO oxidation reactor 211. Reactor 211 oxidizes trace CO to CO₂, which corresponds to process step

G in FIG. 1. Flow conditioning vanes may be inserted at elbows to achieve short flow paths and uniform low pressure drop throughout reactor 211. The effluent purified hydrogen stream is then collected in a concentric diffuser and is sent to exchanger 212 which recovers heat energy into the water feed W. The cooled hydrogen stream is then flashed in separator 213 to remove excess water WW. The hydrogen gas stream P from separator 213 is then suitable for hydrogen users, such as a fuel cell.

Please amend the paragraph beginning on page 14, line 17 as follows:

Yet another illustrative embodiment of the present invention is a method for converting hydrocarbon fuel into a hydrogen rich gas by heating the hydrocarbon fuel to produce a heated hydrocarbon fuel, then reacting the heated hydrocarbon fuel in the presence of a catalyst under desulfurization conditions to produce a substantially desulfurized hydrocarbon, then mixing the substantially desulfurized hydrocarbon with an oxygen containing gas to produce a fuel mixture, then heating the fuel mixture to produce a heated fuel mixture, then reacting the heated fuel mixture in the presence of a catalyst under auto thermal reforming conditions to produce a first hydrogen containing gaseous mixture, then reacting the first hydrogen containing gaseous mixture in the presence of a catalyst under desulfurization conditions to produce a second hydrogen containing gaseous mixture that is substantially desulfurized, then reacting the second hydrogen containing gaseous mixture with a catalyst under water gas shift reaction conditions to produce a third hydrogen containing gaseous mixture with a substantially reduced carbon monoxide content, and then reacting the third hydrogen containing gaseous mixture in the presence of a catalyst under selective oxidation reaction conditions of to produce the hydrogen rich gas. It is intended that this embodiment be able to reduce the carbon monoxide concentration in the hydrogen rich gas to less than 50 ppm. Yet another preferred aspect of this embodiment is utilizing an anode tail gas oxidizer

U.S.S.N. 10/006,879
Amendment
October 13, 2005

including a catalyst for reacting the unconverted hydrogen from a fuel cell under oxidation conditions to create a hot anode tail gas oxidizer effluent. This hot anode tail gas oxidizer effluent can be used to heat integrate with the process and improve the overall energy efficiency of the apparatus.